Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 2, 2017

ENG248 – Unit Operations	DURATION	
	Reading Time:	10 minutes
	Writing Time:	180 minutes

INSTRUCTIONS TO CANDIDATES

The paper has only one section. Answer All Questions.

EXAM CONDITIONS

You may begin writing from the commencement of the examination session. The reading time indicated above is provided as a guide only.
This is a CLOSED BOOK examination
Any non-programmable calculator is permitted
No handwritten notes are permitted
No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 20 Page Book 2 x Scrap Paper

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

THIS PAGE HAS BEEN INTENTIONALLY LEFT BLANK.

Total No of Marks: 100

All questions should be answered in the Answer Booklet provided.
Please Note that All Questions are to be answered.

Marks for each question are indicated. Suggested time allocation: 180 mins

---

Question 1

(a) Consider a first order symbolic reaction: $A \longrightarrow B$. The reaction is carried out in a batch reactor. You want to run the batch until the number of moles of A is reduced to 2% of it's initial value in the constant volume reactor. Calculate the time required for the batch to complete. Specific rate constant is k= 0.25 min^{-1}

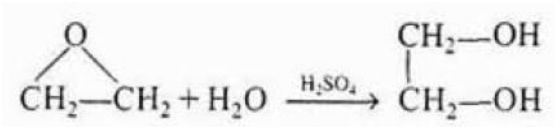
(Marks: 05)

(b) Develop a stoichiometric table for a batch system for the generic reaction below in terms of number of moles and conversion.

$$aA + bB \rightleftarrows cC + dD$$

(Marks: 10)

(c) A CSTR reactor is designed to produce 2 x 10^8 pounds/yr of ethylene glycol. The reaction is first order in ethylene oxide.



It is operated isothermally. A 18 mol/dm^3 solution of ethylene oxide in water is mixed with it's double volumetric solution of water containing 0.9 wt% of H_2SO_4 as catalyst and fed to the CSTR. The specific rate constant is 0.311 min^{-1}. Determine the necessary CSTR volume to achieve 85% conversion.

(Marks: 10)

Question 2

(a) A 60ft long pipe is packed with catalyst pellets of ¼ in diameter. Cross sectional area of the pipe is 0.01414 ft^2. There is 104.4 lb_m/h of gas passing through the catalyst bed in the pipe. The temperature is constant along the length of the pipe at 260°C. The entering pressure is 10 atm. The volume of solid catalyst is 55% of the total bed volume. Viscosity and density of the gas at 260C and 10 atm are 0.0673 lb_m/ft.h and 0.413 lb_m/ft^3, respectively. Evaluate the pressure drop at 2/3 length of the pipe. Pressure in terms of reactor length is expresses below:

$$\frac{P}{P_0} = \left(1 - \frac{2z\beta_0}{P_0}\right)^{1/2}$$

$$where, \qquad \beta_0 = \frac{G(1-\emptyset)}{g_c \rho_0 D_p \emptyset^3}\left[\frac{150(1-\emptyset)\mu}{D_p} + 1.75G\right]$$

where

P	= Pressure
Ø	= Void fraction
g_c	= 4.17 x 10^8 lbm. ft/h^2. lbf
D_p	= Diameter of particle in the bed
µ	= Viscosity of gas passing through the bed
z	= Length down the packed bed of pipe
ρ	= Gas density
G	= Superficial mass velocity

(Marks: 07)

(b) An elementary liquid phase reaction is carried out in batch reactor as given below:

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

The initial concentration of A is 3 mol/dm^3. Specific rate constants are, k_1 = 0.3 h^{-1}; k_2=0.1 h^{-1}. The reaction is heated very rapidly to the reaction temperature, where it is held at this temperature until the time it is quenched. The concentrations of A, B and C at time, t can be expressed as function of initial concentration of A, $C_{A0;}$ rate constants, k_1, k_2 and batch time, t as followings:

$$C_A = C_{A0}e^{-k1t} \; ; \; C_B = k_1 C_{A0}\left[\frac{e^{-k1t} - e^{-k2t}}{k_2 - k_1}\right]$$

$$C_C = \frac{C_{A0}}{k_2 - k_1}\left[k_2[1 - e^{-k1t}] - k_1[1 - e^{-k2t}]\right]$$

I. Determine the time to quench the reaction when the concentration of B will be a maximum.

(Marks: 06)

II. Evaluate overall selectivity and yields at this quench time.

(Marks: 04)

(c) Consider the following parallel reactions to minimize unwanted product:

$$A + B \longrightarrow D : r_D = k_1 C_A^{\alpha 1} C_B^{\beta 1}$$

$$A + B \longrightarrow U : r_D = k_2 C_A^{\alpha 2} C_B^{\beta 2}$$

Select the appropriate choice of reaction schemes with proper justification from the APPENDIX I to maximize selectivity, $S_{D/U}$ for the following combinations of reaction orders:

I. Case 1: reaction orders are $\alpha 1 > \alpha 2$, $\beta 1 > \beta 2$

(Marks: 04)

II. Case 2: reaction orders are $\alpha 1 < \alpha 2$, $\beta 1 < \beta 2$

(Marks: 04)

Question 3

(a) Compare between propeller, turbine and high efficiency impeller in terms of their working principle and applications.

(Marks: 05)

(b) A disk turbine with six flat blades is installed centrally in vertical baffled tank 2m in diameter. The turbine is 0.67m in diameter and is positioned 0.67m above the bottom of the tank. The turbine blades 134 mm wide. The tank is filled to a depth of 2m with an aqueous solution of 50% NaOH at 65°C which has a viscosity of 0.012Pa.s and a density of 1500 kg/m^3. The turbine impeller turns at 80 rpm.

I. What power will be required to drive the impeller? Power consumption is expressed as,

$$P = N_p n^3 D_a^5 \rho \, ;$$

Where, N_p=power number; D_a=impeller diameter; n = number of rotation per second.

APPENDIX II is available for the selection of power number for different impeller. **TABLE Q3(b)** provides values of constants for baffled tanks which may require for power consumption calculation for different impeller.

TABLE Q3(b): Values of constants, K_L (for laminar) and K_T (for turbulent) baffled tanks.

Type of impeller	K_L	K_T
Propeller, three blades		
Pitch 1.0[40]	41	0.32
Pitch 1.5[35]	55	0.87
Turbine		
Six-blade disk[35] ($S_3 = 0.25$, $S_4 = 0.2$)	65	5.75
Six curved blades[40] ($S_4 = 0.2$)	70	4.80
Six pitched blades[39] (45°, $S_4 = 0.2$)	—	1.63
Four pitched blades[35] (45°, $S_4 = 0.2$)	44.5	1.27
Flat paddle, two blades[40] ($S_4 = 0.2$)	36.5	1.70
Anchor[35]	300	0.35

(Marks: 05)

II. It is proposed to use this tank for neutralizing the NaOH solution with stoichiometrically equivalent quantity of nitric acid. How long will it take for the neutralization to be complete if you operate the vessel at laminar flow of Re =1000? Compare the time obtained with the time required for unbaffled tank for the same type of impeller. **APPENDIX III** is available for selecting mixing time factor with change in Reynolds number.

(Marks: 05)

(c) In a 1-2 shell and tube heat exchanger hot and cold fluid in at 240°C and 70°C. The cold fluid exits at 120 °C. The exchanger and fluid properties are: Mass flow rates: m_{hot} = 3000kg/h; m_{cold} = 2400 kg/h; Heat capacities: $C_{p,hot}$ = 2300 J/kg. °C; $C_{p,cold}$ = 4180 J/kg. oC; Overall heat transfer co-efficient, (U) x heat transfer area, (A) = 1.65 x 10^7 W/°C. Effectiveness versus number of transfer units, NTU of the 1-2 exchanger is shown in **FIGURE Q3(c)**.

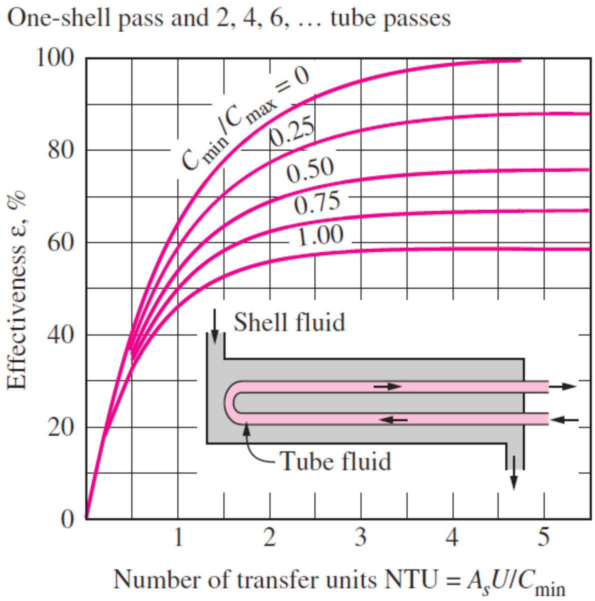


FIGURE Q3(c): Effectiveness versus NTU for 1-2 exchanger

I. Determine the exit temperature of the hot fluid.

(Marks: 05)

II. What is the correct mean temperature drop in this exchanger? Correction factor for 1-2 exchanger is available in **APPENDIX IV.**

(Marks: 05)

Question 4

(a) A furnace wall consists of 200 mm of refractory fireclay brick, 100mm of kaolin brick and 6 mm of steel plate. The fire side of the refractory is at 1150°C and outside the steel is at 30°C. There is 50 mm layer of air between the layers of kaolin brick and steel. You are required to fill this air gap with equivalent steel. Thermal conductivities for fireclay, kaolin brick and steel are 1.7, 0.11 and 45 W/m°C, respectively. Determine the heat loss from the wall.

(Marks: 06)

(b) Benzene at it's boiling point 80 °C is condensing at atmospheric pressure on the outside of a 30mm steel pipe and air at 15 °C flowing within at 5 m/s. The pipe wall is 4 mm thick. Convective heat transfer co-efficient for inside and outside fluid streams are 20 W/m^2 °C and 1200 W/m^2 °C, respectively. Thermal conductivity of the steel pipe is 45 W/m °C.

I. Calculate the overall heat transfer co-efficients based on both inside and outside areas. Comment on your obtained results.

(Marks: 08)

II. Determine the temperatures of the inside and outside surface of the metal pipe.

(Marks: 06)

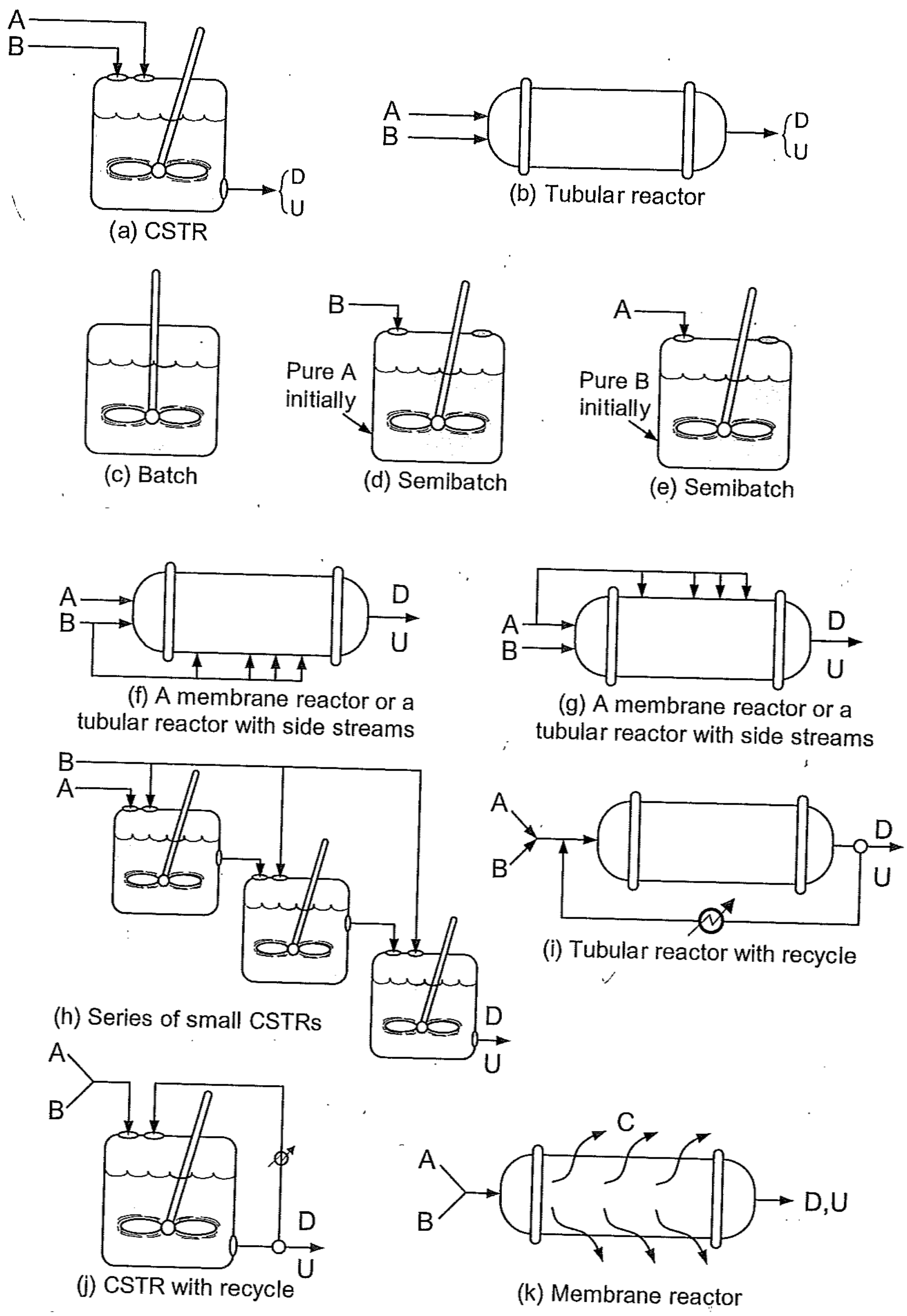
(c) A 1.0-kW heater is constructed of a glass plate with an electrically conducting film that produces a constant heat flux. The plate is 60 cm by 60 cm and placed in an airstream at 27∘C, 1 atm with u_∞ = 5 m/s. The fluid properties at 133∘C (actual film temperature) are: thermal conductivity, k = 0.034 W/m°C; viscosity, μ = 1.85 x10^{-5} kg.m/s; density, ρ = 1.18 kg/m^3; heat capacity, c_p = 1.006 kJ/kg°C. Calculate the average temperature difference along the plate which is expressed as,

$$\overline{T_w - T_\infty} = \frac{q_w L/k}{0.6795\ \mathrm{Re}_L^{1/2}\ \mathrm{Pr}^{1/3}}$$

Where, *Tw* = wall temperature, T_∞= fluid stream temperature; *qw* = heat flux along the wall surface; *L*= length of the wall, *Re* = Reynolds number = $u_\infty \rho L/\mu$; *Pr* = Prandtl number = $\mu Cp/k$.

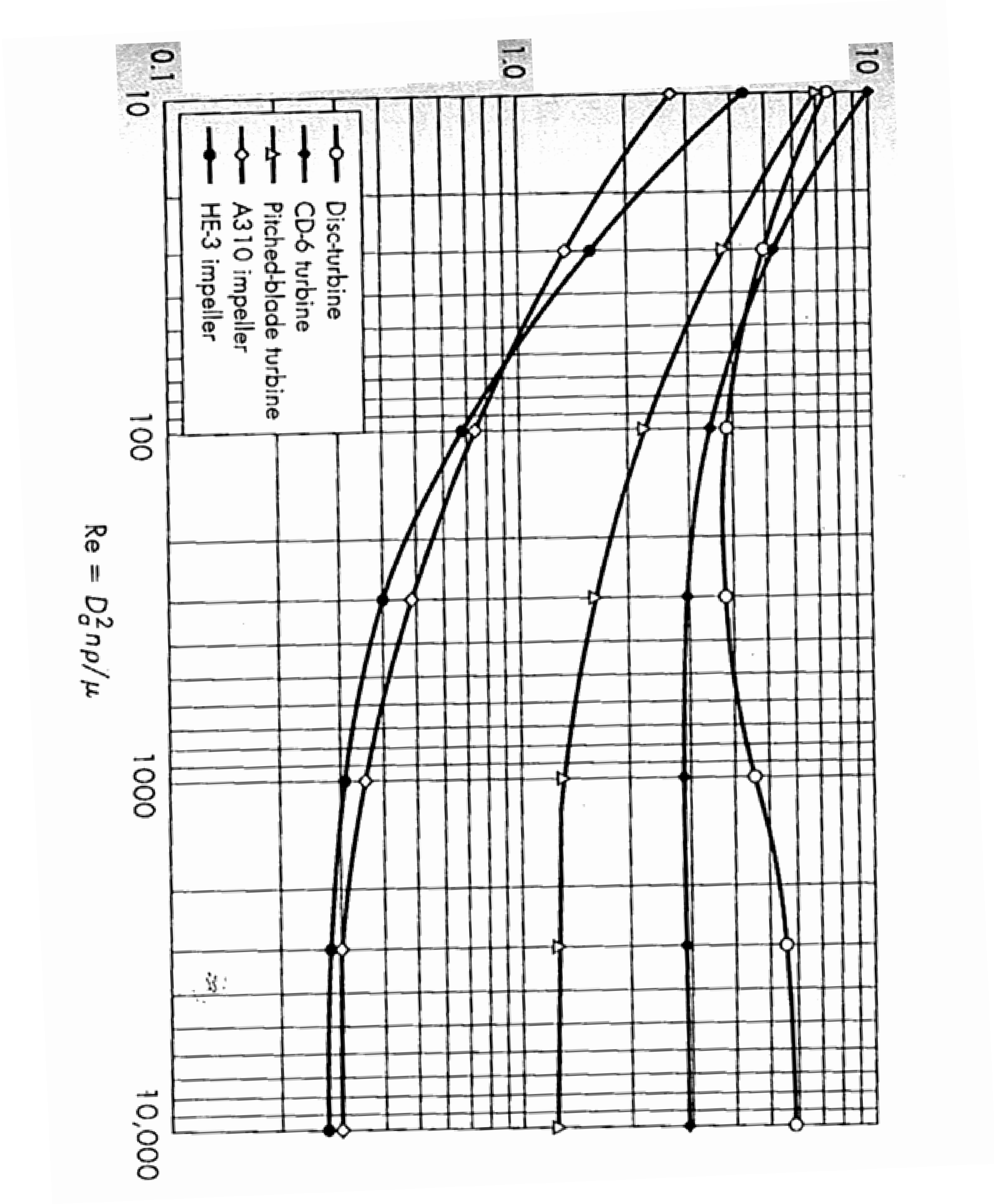
(Marks: 05)

APPENDIX I: Different reactors and schemes for maximizing selectivity. Note unreacted reactants also exit the reactors along with products:

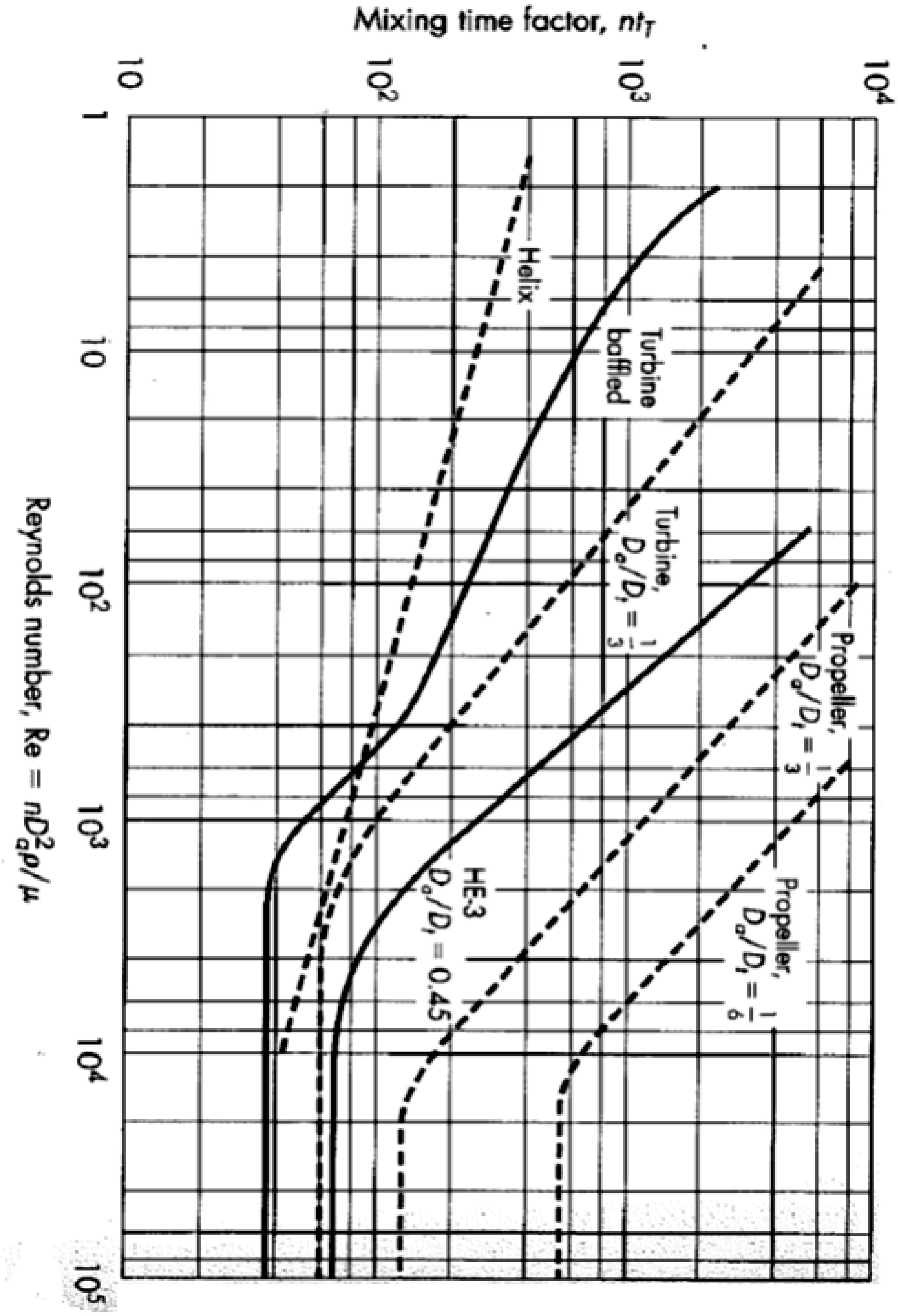


APPENDIX II: Power number N_p versus Reynolds number Re for turbines and high efficiency impeller.

$$N_p = P/n^3 D_a^5 \rho$$



APPENDIX III: Mixing times in agitated vessels. Dashed lines are for unbaffled tanks; solid lines are for baffled tank



APPENDIX IV: Correction LMTD in 1-2 exchanger. F_G is correction faction, η_H is heating effectiveness.